Chapter 1

Geoinformatics for applied coastal and marine management

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1.1 THE CONTEXT: COASTAL AND MARINE SPACES, AND THE NEED TO MANAGE THEM

In the 21st Century, the world is becoming increasingly dependent on the economic, social and environmental benefits derived from ocean and coastal services and resources. This is of course primarily true of those countries that have coastlines but, as Bruce McCormack has suggested in the Preface to this book, even those communities that lie far inland from the sea will benefit as well. The "ocean economy" has become a recognized and measured contributor to national GDP. According to the national account of many countries, the ocean economy and marine-based industries may produce from 1% to 5% of their GDP (Park and Kildow, 2014). Not only has there been greater emphasis on implementing strategies to develop the economic sector, but there is also an increasing urgency for protection of marine resources. This is mirrored by Sustainable Development Goal 14 which is to conserve and sustainably use the oceans, seas and marine resources for sustainable development.

In 2012 for example, it was projected that the Irish Ocean Economy would deliver approximately 0.8% of GDP by 2014 (€ 1.4 billion) and employ 18,480 people (FTE; Vega *et al*. 2012). For 2013/4, the United States of America measured an Ocean Economy contribution of 2.2% to GDP (US$ 359 billion) and employed 137 million people (Kildow *et al*. 2016). The ocean economy also offers opportunity for the promotion of economic growth, environmental sustainability, social inclusion and the strengthening of fisheries and aquaculture, renewable marine energy, marine bio-prospecting, marine transport and marine and coastal tourism. All of these sectors offer growth and development opportunities for coastal states and, especially, for Small Island Developing States (SIDS; UNCTAD 2015).

However, the growth and development opportunities of the ocean economy are tempered by increasing and complex challenges facing coasts and oceans. These include the unsustainable extraction of marine resources, marine pollution, alien invasive species, ocean acidification, climate change impacts, and the physical alteration and destruction of coastal and marine habitats (UNDESA 2014).

Human-induced increases in atmospheric concentrations of greenhouse gases are expected to cause much more rapid changes in the Earth’s climate than have been experienced for millennia. These may have a significant effect on coastal ecosystems, especially estuaries and coral reefs, which are relatively shallow and already under stress because of human population growth and coastal developments. Climate change may decrease or increase precipitation, thereby altering coastal and estuarine ecosystems. Wind speed and direction influence production of fish and invertebrate species, such as in regions of upwelling along the U.S. West Coast. Increases in the severity of coastal storms and storm surges would have serious implications for the well-being of fishery and aquaculture industries. Sea-level rise may inundate or cause migration of important coastal ecosystems, such as mangroves and tidal mudflats, which may be important breeding habitats for fish and other deep-sea organisms in their larval stages. The immense area and the modest extent of our knowledge of the open ocean hamper predictions of how ocean systems will respond to climate change

Further complexity of the ocean’s economy arises from the multilayer regulatory framework under the United Nations Convention on the Law of the Sea (UNCLOS) and other national, regional and multilateral as well as sectoral governance regimes (UNCTAD 2014). This requires the development of a more coherent, integrated and structured framework that takes account of the economic potential of all marine natural resources, which include seaways and energy sources located in the ocean space.

It is within this context that there is a growing need to know enough about natural system, processes and rates of consumption in order to make wise decisions regarding the simultaneous protection and use of natural resources. Even though about 70% of the planet’s surface is covered by ocean water, humans have only effectively explored less than 10% of this, and we have mapped even less than that in any detail. There is thus a growing urgency attached to the need for more comprehensive and reliable data relating to the marine environment. This of course will require both political willingness, on an international level, and also corresponding economic investment but, when compared to other areas of major current outlay the costs should not be seen as prohibitive: it was suggested recently that mapping the whole of the world’s oceans would cost about US $3 billion (approximately the same as a single mission to Mars), and about 200 ship-years to complete (Holden, 2015).

1.2 THE ROLE OF SPATIALLY-ENABLED INFORMATION AND COMMUNICATION TECHNOLOGIES (ICT)

In recognition of the many problems that have arisen in the past through inappropriate use and management of the coast, a new, more "environmentally-oriented" ethos of coastal management is emerging. Based on more holistic, trans-disciplinary and integrative principles (sometimes simply referred to as “joined-up thinking”), this new approach is aimed at sustainable management of resources for the benefit of all stakeholders. A similar evolution may also be seen at work in the context of ocean management, with the prevailing sectorial approach being increasingly placed in the broader contexts of international law and agreements, and the emergence of marine spatial planning as a framework for addressing concerns and reconciling potentially conflicting interests.

For it to work, this new philosophy depends on a thorough understanding the entities and relationships at work in marine and coastal systems. Governments and the scientific community alike have responded to this need, leading to a major paradigm shift in scientific research (Birkin, 2013), in which an earlier focus on experimentation and reasoning is being replaced by a preoccupation with analysis of the increasing volumes of data being made available at unprecedented spatial and temporal scales. For these and other reasons, spatially-enabled information and communication technologies (ICT) are increasingly being used by coastal and marine scientists and administrators to assist them in their work.

Scientific applications have frequently been at the forefront of driving computer and information technology (Baru, 2011). In most domains, the pioneering applications of these tools were limited by the size and expense of computers, and by the limited storage, processing and graphic output capabilities of the machines available at the time (Marble, 2010). This was certainly the case for early applications of ICT to coastal and ocean science (Bartlett, 2000; Wright, 2000), where the challenges were further compounded by the complexity of marine and coastal environments, and the need to devise appropriate digital formats and structures to represent these particular geographies. But, as Marble and Peuquet observed, in most disciplines "there are problems which prove intractable when first encountered, but which are reduced within a few years through the application of additional theoretical insights as well as significant amounts of hard work and luck" (Marble and Peuquet, 1983). As the chapters in this book will demonstrate, many of the early obstacles have now been addressed and, while a number of challenges remain, and much research and development still needs to be undertaken, the application of geospatial technologies to the demands of marine and coastal management is rapidly becoming routine.

Until the early 1980s, the main contribution of information technology to marine and coastal studies consisted primarily of stand-alone programs, written in FORTRAN and other early languages, to address specific tasks in the fields of biological oceanography, chemical oceanography, geoscience, physical oceanography, navigation and charting, and the retrieval and editing of ocean data (for a comprehensive annotated listing of early computer programs for oceanographic data management and analysis, including details of the programming languages used and the computers for which they were developed, see Dinger, 1970). By the early 1980s, however, collections of programs for spatial data handling were being progressively brought together and packaged in the form of integrated, general-purpose geographical information system (GIS) toolboxes (Coppock and Rhind, 1991; Goodchild, 2000; Chrisman, 2005, 2006; Hoel, 2010). Although in their early days these systems were primarily aimed at terrestrial applications and their users, their potential to also address coastal and marine needs soon became recognized (Bartlett, 1993a, 1993b, 2000; Wright, 2000). Since then, the range and scope of these applications has expanded rapidly as existing technologies have improved, new ones have emerged, and extended methodological frameworks (Green and King, 2003; Bartlett and Smith, 2004; Wright *et al*., 2007; Green, 2010) have been developed.

Today, spatial information technologies are ubiquitous and no longer the preserve of the pioneer or the specifically-trained specialist. As well as their presence in the workplace, they are also pervasive and frequently to be found embedded in consumer products, including mobile phones, tablet computers, on desktop computers, in car dashboards, on the bridges of ships, on the wrists of athletes, incorporated into people's clothing, and in a myriad other locations that would have been barely imaginable just a few years ago. Furthermore, applications based on these technologies increasingly involve the convergence and integration of multiple elements drawn from an ever-widening range of possible ingredients, including geographical information systems (GIS), digital cartography, optical and microwave remote sensing, spatial database systems, Internet and mobile phone technologies, global satellite positioning systems, Light Detecting and Ranging (LiDAR) and other laser-based survey techniques, gaming engines, digital photogrammetry, sensors and autonomous data collecting devices and others.

The term geoinformatics has been adopted independently by a number of geospatial and geoscience disciplines (Keller, 2011) to collectively describe these technologies, their applications, and the scientific disciplines that underpin them, particularly since the closing years of the 20th Century (Gundersen, 2007). For Fotheringham and Wilson (2008:1), 'geoinformatics' is synonymous with the related concepts of geocomputation, geoprocessing and geographic information science (sometimes abbreviated to GISci, to distinguish it from Geographical Information Systems, GIS – see for example Mark, 2002, Longley *et al*., 2011, 2015,). It is also closely related to the word 'geomatics', defined by Gagnon and Coleman as "a field of scientific and technical activities which, using a systemic approach, integrates all the means used to acquire and manage spatially referenced data as part of the process of producing and managing spatially based information" (Gagnon and Coleman, 1990).

Technical and semantic interoperability between system components, along with greater accessibility of geoprocessing resources, "improve the application of geospatial data in various domains and help to increase the geospatial knowledge available to society" (Zhao *et al*., 2012). This is especially important for marine and coastal management, where multiple datasets, collected by different agencies through many different means, have to be integrated, compared and analysed together. These issues of integration and data compatibility are increasingly being addressed through the development of dedicated spatial data infrastructures (Longhorn, 2004; Bartlett *et al*.,2004; Strain *et al*., 2006; Wright, 2009), comprising standards for data, computer hardware and software; geoportals designed to make easier the task of data discovery and access; and rules and regulations that define the legal, financial and institutional contexts within which geoinformatics methods and applications can and should operate.

1.3 CASE STUDY: CORK HARBOUR

One of the largest natural harbours in the world, Cork Harbour on the south coast of Ireland (Figure 1.1) epitomises both the great diversity of maritime activities prevalent in a modern economy, and also the range of applications of spatial information technologies to support these. In physical terms, the harbour is a former river valley, flooded as world sea-levels rose at the end of the last ice age, approximately 10,000 years ago. Its primary river, the River Lee, feeds into the harbour in the northwest, and Cork City, the second city of the Republic of Ireland, is built on former marshland at the river's lowest bridging point. Several other, smaller, towns and settlements are also to be found around the shores of the harbour.

[FIGURE 1.1 ABOUT HERE (suggest perhaps oriented in landscape format on the page if possible?)]

Many locations within and around Cork Harbour are of major environmental and ecological significance. The waters of the harbour are home to grey seals (*Halichoerus grupus*), common seals (*Phoca vitulina*), and are occasionally visited by common dolphins (*Delphinus delphina*), bottlenose dolphins (*Tursops truncatus*) and other cetaceans. Closer to shore, and especially in the inner harbour area, the mudflats, saltmarshes and shingle shorelines host large populations of feeding, breeding and, in some cases over-wintering waders, wildfowl and other birds, as well as numerous otters (*Lutra lutra*). This has led to several sites being designated as Special Protection Areas, Ramsar sites and Special Areas of Conservation. While primary responsibility for designating these rests with the National Parks and Wildlife Service (a Government Agency), numerous voluntary bodies and non-governmental organizations (NGOs) also play important roles in and monitoring them and ensuring their well-being. Several of these "citizen science" initiatives use web-enabled GIS tools to facilitate the collection, analysis and reporting of observation data by members of the public: examples of this would include the annual Coastwatch survey (http://coastwatch.org/europe/survey/) and the BirdTrack online bird recording scheme, developed jointly by BirdWatch Ireland, the British Trust for Ornithology, the Royal Society for Protection of Birds, The Scottish Ornithologists' Club and the Welsh Ornithological Society (http://www.bto.org/volunteer-surveys/birdtrack/about). The role of volunteered geographical information in coastal and marine management is discussed by Goldberg *et al*, in an international context, in Chapter 7 of this book.

Historically, Cork Harbour has always been an important locus for international shipping and commerce and, by the end of the 18th Century, the port of Cork was Ireland's leading transatlantic shipping port (Rynne, 2005). Initially many these port activities were located on the quaysides of Cork city itself but, by the early years of the 19th Century, extensive silting up of the shipping channels led to the gradual migration of commercial and industrial activities down-river to the outer harbour area. Even today, periodic dredging of the main shipping channels is required, both in the inner and outer harbour areas, and several formerly thriving lesser fishing and trading ports around the harbour are now no longer viable. Regular surveying and monitoring of the bathymetry of the seabed and shipping channels, as described by Scott *et al*. in Chapter 2 of this volume, is essential to inform this task and is undertaken regularly (Figure 1.2); while a buoy containing sensors for a range of meteorological and marine environmental parameters is moored just off the harbour entrance. The increasingly important role of sensors for collecting data about the marine environment is discussed by Zhang *et al*. in Chapter 5.

Ireland’s National Space Centre is located at Elfordstown, about 15km inland to the north of the harbour (http://nationalspacecentre.eu/). Originally built in the early 1980s as a link in the Eutelsat network to facilitate transatlantic air traffic and telecommunications, the site was redeveloped and reopened in 2010 as Europe’s most westerly teleport and data download station, where one of its primary areas of specialization is in the use of Earth observation for maritime surveillance. Lück-Vogel explores recent developments in satellite remote sensing and Earth observation, as a further important source of geospatial data for marine and coastal management, in Chapter 4 of the present volume, Saunders examines maritime surveillance from the perspective of international legal conventions and agreements in Chapter 9, and Mathews and Power explain how geoinformatics and telecommunications are assisting in the task of policing Irish territorial waters, as well as in search and rescue operations in the Mediterranean, in Chapter 15.

[FIGURE 1.2 ABOUT HERE]

About 10 million tonnes of freight is currently handled by the port of Cork annually. Ireland’s only oil refinery, located on the eastern side of the harbour near its outlet to the sea, accounts for over 55% of this freight, and 28% of the ship tonnage (Port of Cork Company, 2015), while three container terminals in the harbour handle between them a considerable proportion of the rest. Across the water, on the western side of the harbour, lies the Ringaskiddy deepwater terminal, with container and bulk cargo handling facilities, as well as passenger and car ferry connections with France and, until recent years, the UK.

Ringaskiddy is also home to IMERC, the Irish Maritime and Energy Research Cluster, launched in 2010 as a joint initiative of University College Cork, Cork Institute of Technology and the Irish Naval Service (www.imerc.ie). This campus is intended to become a world-leading specialist centre of expertise for research and development in marine energy (renewables and offshore hydrocarbons); maritime information and communications technologies (ICT); shipping logistics and transport; maritime security and safety; and yachting products and services. The campus includes the National Maritime College of Ireland, which specializes in addressing the training and research needs of the Irish and international maritime sector (http://www.nmci.ie/); the MaREI centre for marine and renewable energy (http://marei.ie/); and the LIR National Ocean Test Facility (http://www.lir-notf.com/) The role of geoinformatics for marine renewable energy is examined by Green in Chapter 12 of the current volume.

The town of Cobh, almost directly opposite the entrance to Cork Harbour, has important heritage and historical significance as the embarkation point for over 1 million emigrants, who set sail from Ireland to Britain, America, Canada, Australia and other places of refuge during, and especially after, the Great Irish Famine of the 1840s and 50s (Foster, 2005; Crowley et al., 2012); and also as the last port of call of the steamship *Titanic*, on its maiden voyage across the Atlantic. Today, Cobh has Ireland’s only dedicated terminal for cruise liners (Figure 1.3), and is thus an important centre for the tourism and heritage sector. In 2014, 58 cruise liners, with a gross tonnage of 3.5 million tonnes, brought over 120,000 passengers and crew to the region (Port of Cork Company, 2015), and a small but locally important trawler fishing fleet. In Chapter 14 of this volume, Adam Weintrit outlines the increasing role of electronic charting and automatic vessel identification systems in ensuring safe navigation of shipping, while Nishida et al., in Chapter 13, discuss the specific role of geoinformatics in the context of the fishing industry.

[FIGURE 1.3 ABOUT HERE]

Finally, in the centre of the harbour and directly across the channel from Cobh, lies the main base of the Irish Naval Service on Haulbowline Island. The INS has a number of defence and other tasks that bring an important international dimension to their work, including monitoring and protection of fisheries in one of the largest marine sectors within the European Union, policing operations in Irish territorial waters and, in recent years, actively supporting responses to the migrant crisis in the central and eastern Mediterranean (see chapter 15, by Mathews and Power).

Although not as vulnerable to environmental hazards as several other coastal locations might be, the communities and settlements around Cork Harbour and area are subject to the impacts of storms, flooding and coastal erosion (Figure 1.4), all of which are projected to increase in frequency and severity under conditions of predicted climate change (Cummins and O'Donnell, 2005; Devoy, 2008; Kopke and O'Mahony, 2011). Cork City itself is particularly prone to flooding, due largely to its location at the head of the harbour and on the delta of the River Lee (Crowley et al., 2005). However the opening decade of the 21st Century saw rapid expansion and development of many settlements around the harbour and, in some cases, houses appear to have been built in areas that longer-term community wisdom spanning multiple generations knew to be prone to flooding. Examples such as this illustrate the value of seeking out and incorporating traditional knowledge of place, when drawing up plans for coastal development and management. In Chapter 10, Shankar Aswani outlines how approaches based on participatory GIS can assist in acquiring and using this traditional understanding of the sea and its characteristics; while the application of geoinformatics technologies for more formal assessment, reduction of and response to coastal hazard and vulnerability is discussed by Bonetti and Woodroffe in the final chapter of this book.

[FIGURE 1.4 ABOUT HERE]

The multiplicity of uses and economic activities in Cork Harbour and its hinterland, as outlined in this section, inevitably puts pressure on the resources and environments it contains. This in turn can (and occasionally does) lead to conflict and potential disputes between stakeholders. It also requires appropriate management frameworks to give coherence and longer-term vision to policies and decision-making aimed at reducing conflict. For Cork this is particularly significant, since management of the harbour, its environment and its resources is devolved and shared across a number of statutory and other agencies, including the Marine Institute, the Environmental Protection Agency, the Office of Public Works, the County and (Cork) City councils, and a number of other bodies. The concepts of Integrated Coastal Zone Management (ICZM) and Marine Spatial Planning (MSP) offer frameworks through which integration and more sustainable management of coastal and ocean spaces might be achieved, and a number of studies (e.g. O'Mahony *et al*., 2009, 2014; Queffelec *et al*., 2009) have investigated how they might be applied within the harbour. The origins, applications and significance of ICZM and MSP, and the role of geoinformatics technologies in assisting these, is discussed in a wider context by Lauren McWhinnie and Kate Gormley in Chapter 8 of this book, while Lassoued and Leadbetter (Chapter 6) explain how and why a consideration of ontologies is important in order to ensure compatability and interoperability of databases, technologies and working practices when seeking to develop sustainable and inclusive approaches to coastal management.

In Section 1.1 of the present chapter, the point was made that large tracts of ocean floor have yet to be surveyed and mapped in any detail. The INFOMAR programme, outlined by Scott *et al*. in Chapter 2, is helping to address this need with regard to the Irish continental shelf while, in Chapter 3, Paul Murphy and Andy Wheeler discuss their analysis of the Gollum Channel complex on the Porcupine Bank, approximately 100 km from the Irish coast, and demonstrate how high-resolution bathymetric data from INFOMAR, along with advanced GIS tools, can support fundamental oceanographic science as well as economic purposes.

Looking even further afield, in Chapter 11 of this volume, Barry *et al* present the work of the Arctic Council, and the role of geoinformatics technologies in supporting this. One of the main current concerns in the Arctic is the increasing extent of ice-melt in the summer months, widely accepted as an indicator and consequence of anthropogenic-induced climate change. One of the many implications of this is the prospect that shipping lanes through the Arctic Ocean, whether along the north coast of Russia or via the north of Canada, will remain ice-free and navigable for longer in the year, offering far shorter, cheaper and quicker trade routes between Europe and markets.in Asia and the western seaboard of the United States. While this could clearly be of benefit for port authorities in Europe, expansion of these northern sea-routes is likely to have adverse impacts on many ports in the southern hemisphere, including Durban, the principal commercial port in South Africa in terms of number of ship calls and number of containers handled (Jones, 2014), and currently a key node in shipping between the Atlantic and Indian Oceans. This example serves to further illustrate the increasingly important globalized nature of society's relationship with the sea, a relationship that spans and connects in so many ways the physical and natural environment with the socio-economic and cultural aspects of 21st Century living.

Inevitably, in selecting the chapters, examples and case studies for inclusion in this book, countless other applications of spatial technologies to marine and coastal management issues had to be omitted. Nonetheless taken together, the chapters presented here do serve to illustrate the diversity of human uses of and demands on the world's oceans and coasts, the increasing importance of management strategies to enable the search for a more sustainable relationship between human society and the marine environment and, linking these, the growing role of geoinformatics technologies in facilitating this.

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